Search for NSI with IceCube DeepCore

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Neutrino Non-Standard Interactions (NSI)

- naturally emerge from many **neutrino mass models**

type-II (triplet) seesaw

inverse seesaw

$U(1)'$ gauge symmetry

Zee-Babu model

R-parity violating SUSY

- usually parameterised in terms of **effective four-fermion Lagrangian**

$$-2\sqrt{2}G_F \sum_{f=e,u,d} \left[\bar{\nu}_\alpha \gamma^\mu L \nu_\beta\right]\left[\bar{f}\gamma_\mu \left(\epsilon^{fL}_{\alpha\beta} L + \epsilon^{fR}_{\alpha\beta} R\right) f\right]$$

NC NSI (in propagation)

- *effective* couplings in low-energy regime ($q^2 \ll m_X^2$):

$$\epsilon \sim \mathcal{O}\left(\frac{G_X}{G_F}\right) \propto g_X^2 \frac{m_W^2}{m_X^2}$$

X: new mediator

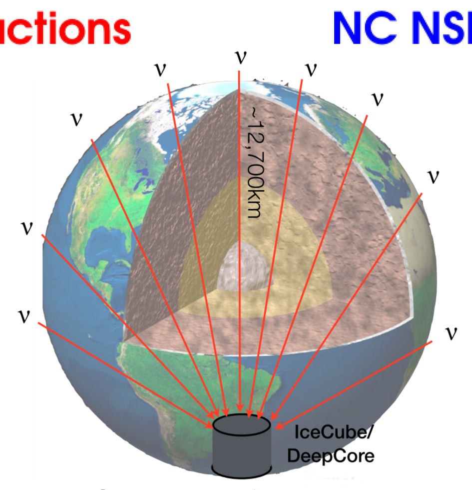
Neutrino oscillation in presence of NSI

- NSI give rise to **generalised matter potential** in a medium

$$\hat{H} = \frac{1}{2E} U \mathrm{diag}\left(0, \Delta m^2_{21}, \Delta m^2_{31}\right) U^\dagger + V_e(r) \left(\mathrm{diag}(1,0,0) + \sum_f \frac{N_f(r)}{N_e(r)} \begin{pmatrix} \epsilon^f_{ee} & \epsilon^f_{e\mu} & \epsilon^f_{e\tau} \\ \epsilon^{f*}_{e\mu} & \epsilon^f_{\mu\mu} & \epsilon^f_{\mu\tau} \\ \epsilon^{f*}_{e\tau} & \epsilon^{f*}_{\mu\tau} & \epsilon^f_{\tau\tau} \end{pmatrix}\right)$$

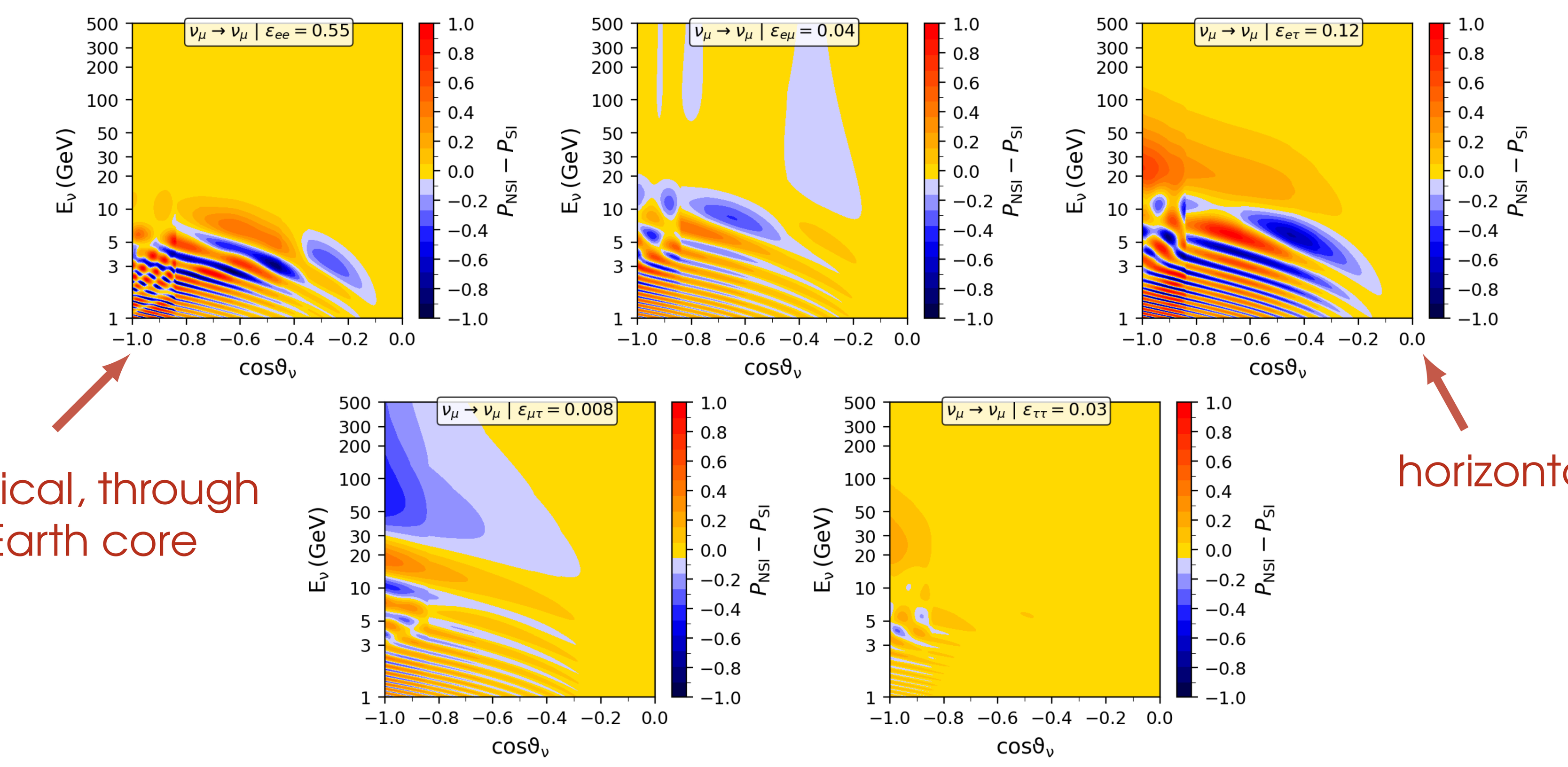
vacuum SM weak interactions NC NSI

- relevant for **atmospheric neutrino propagation through the Earth**



- impact of NSI couplings ($\epsilon^d_{\alpha\beta}$) on **atmospheric ν_μ survival probabilities**

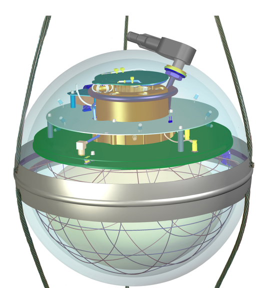
(couplings at upper end of global 90% C.L. allowed range)



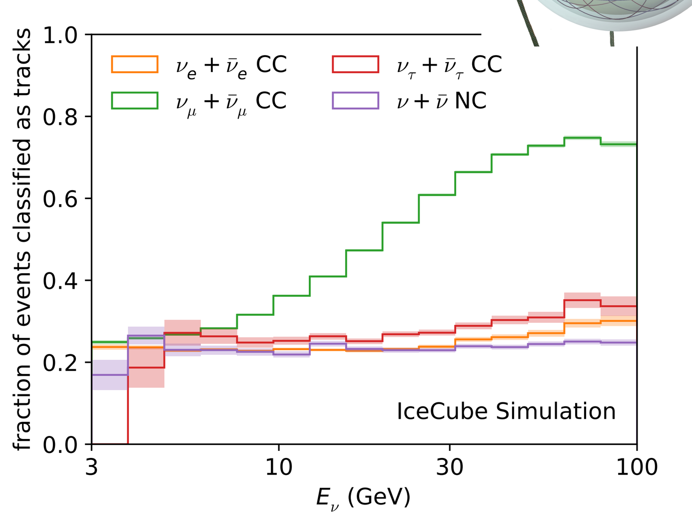
$\Rightarrow$ **disappearance of high-energy ν_μ flux due to $\epsilon_{e\mu}$ & $\epsilon_{\mu\tau}$**

$\Rightarrow$ **increased survival at medium energy due to $\epsilon_{e\tau}$ & $\epsilon_{\tau\tau}$**

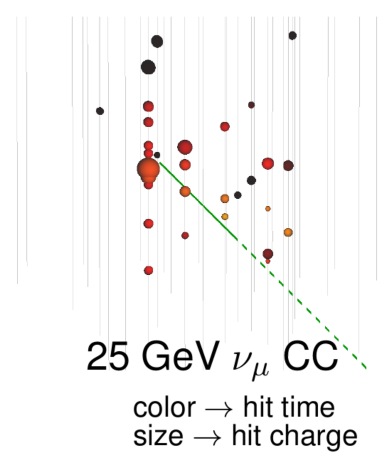
IceCube DeepCore



- ***IceCube***: cubic-kilometre in-ice Cherenkov detector at geographic South Pole
- about 5000 optical modules on 86 strings, at depths between 1.5 km–2.5 km
- ***DeepCore***: infill array at deep centre of IceCube, lowers energy threshold to 5 GeV



measure atmospheric neutrino oscillations

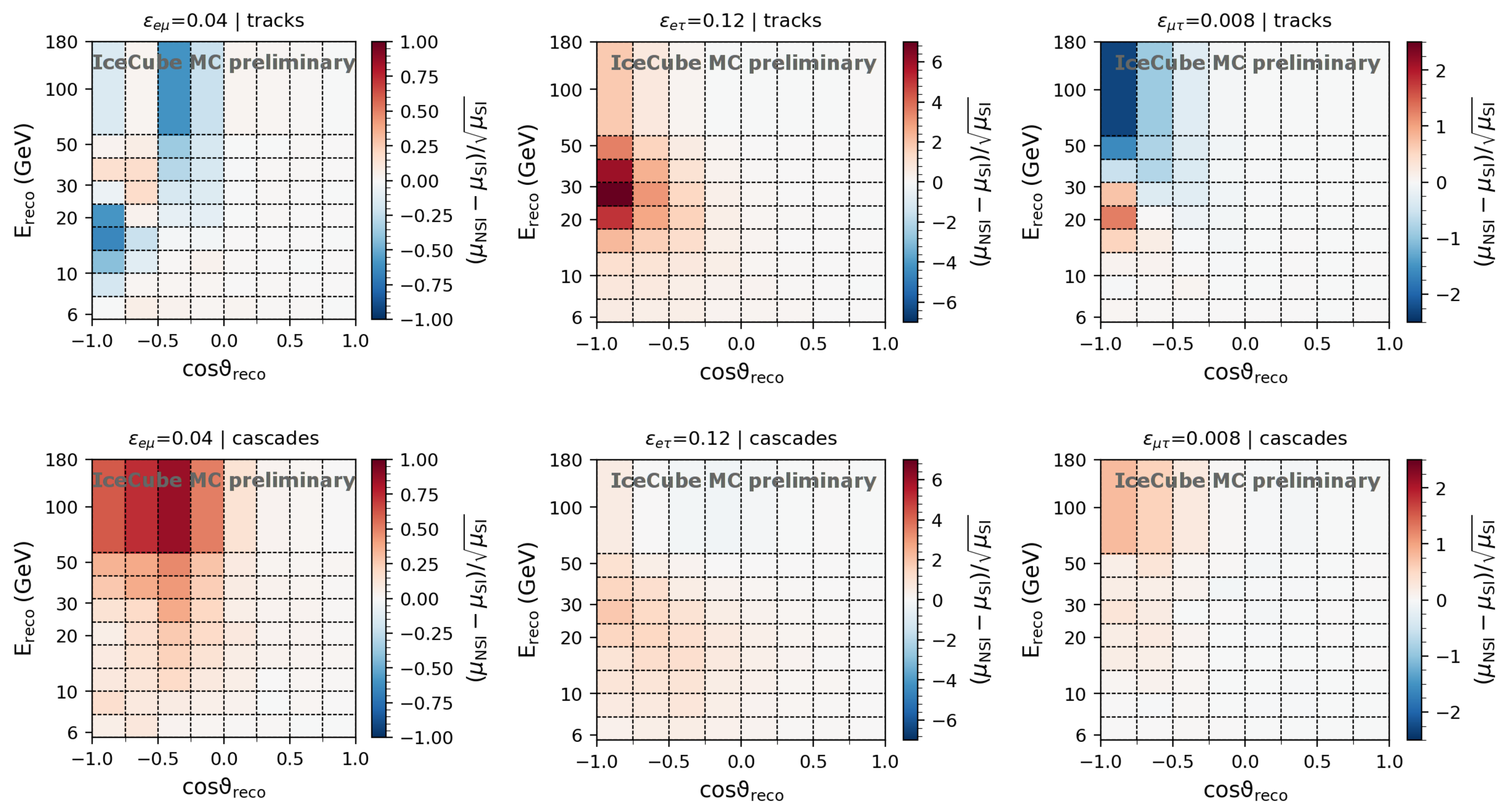


- no event-by-event discrimination between ν and $\bar{\nu}$
- energy-dependent efficiency of $\nu_\mu + \bar{\nu}_\mu$ CC identification

"tracks" vs. "cascades"

MC signal expectation (FCNC NSI)

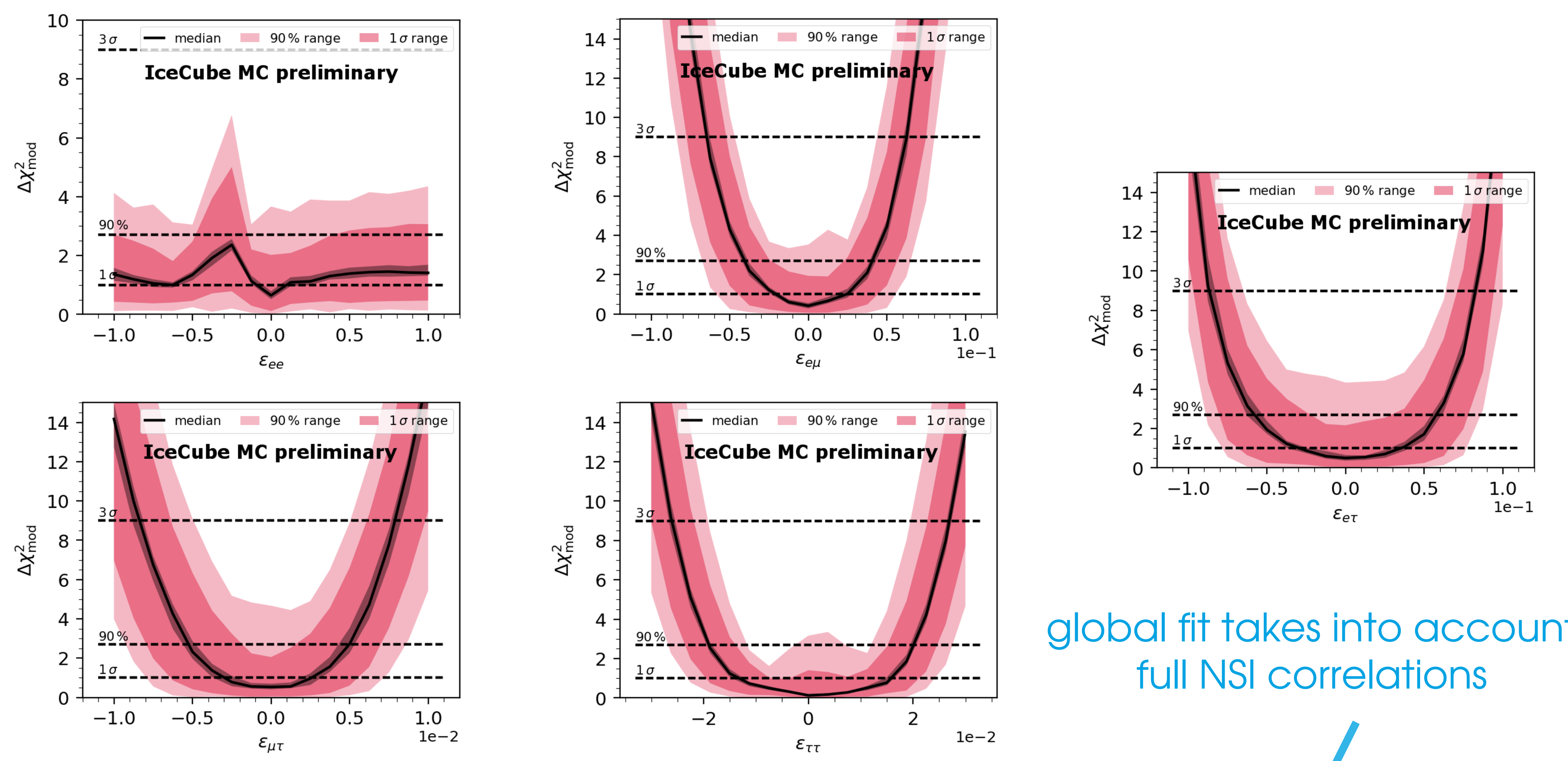
- 3-year **cascade + track** dataset extended to **180 GeV** **(expect about 50k events in 3 years)**



signals across all energies and full upgoing zenith range (note different colour scales)

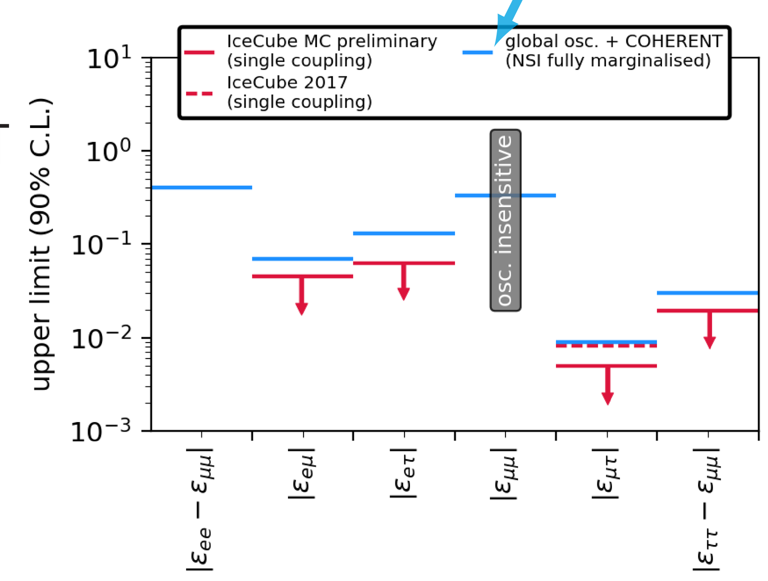
NSI sensitivity

- test single real NSI coupling $\left(\epsilon_{\alpha\beta} \equiv \epsilon^{dV}_{\alpha\beta} = \epsilon^{dL}_{\alpha\beta} + \epsilon^{dR}_{\alpha\beta}\right)$ at a time

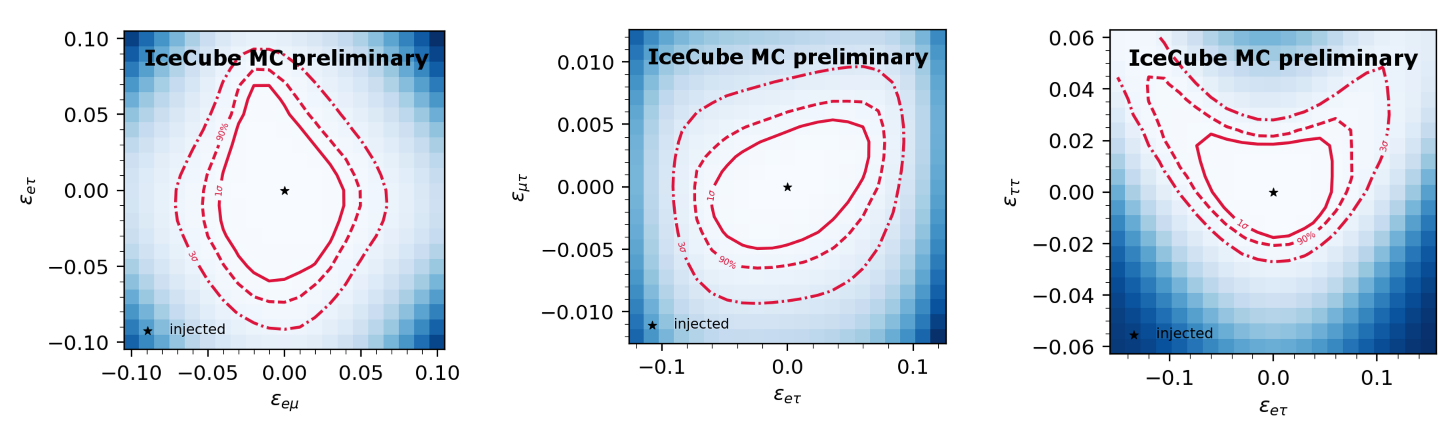


global fit takes into account full NSI correlations

- one-by-one limits compared to a global fit to oscillation + COHERENT data (**valid for $m_X \gtrsim 10$ MeV**) and previous measurements



- **constraints from oscillation experiments independent of scale of new physics**
- all-flavour search → data sample able to simultaneously constrain multiple NSI couplings, for example:



References

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